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ABSTRACT

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Conceptual Change Text: A Supplementary Material to Facilitate Conceptual Change in Electrochemical Cell Concepts

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Abstract

The main purpose of this study was to investigate the effectiveness of conceptual change text (CCT) oriented instruction over traditionally designed instruction on students' understanding of electrochemical (galvanic and electrolytic) cell concepts. The subjects of the study consisted of 64 students from the two classes of a high school in Turkey. One of the classes was randomly assigned to experimental group, which was exposed to CCTs, and the other class was determined to be the control group, which was exposed to traditionally designed instruction. The results of ANCOVA indicated that students experiencing CCTs had better understanding of electrochemical cell concepts than students experiencing traditional instruction when their science process skills and prior electrochemical cell concepts understanding were statistically controlled. In the light of the findings of this study, it is suggested that CCTs can be used as a supplement to classroom instruction to promote students' understanding science concepts that are more in line with the scientific community.

Introduction

Since early 1970's research in science education has enriched our understanding of the effect of prior knowledge on conceptual understanding of science concepts. It has been widely accepted that learners use preexisting conceptions to make sense of the newly presented knowledge (Driver & Easly, 1978; Zietsman & Hewson, 1986). Since learners base their understanding of the new knowledge on their previously learned conceptions, they may develop concepts different from those accepted as correct by the scientific community even after formal instruction. These alternative ideas have been given several names in the literature including misconceptions (Cho, Kahle & Nordland, 1985; Griffiths & Grant, 1985), alternative frameworks (Driver & Erickson, 1983) and children's science (Gilbert, Osborne & Fensham, 1982).

A growing number of studies has shown that students of all ages have a wide spectrum of misconceptions regarding chemistry. One active area of research on students' misconceptions in chemistry is the topic of electrochemistry. The results of student and teacher surveys indicated that students found this topic difficult (Butt & Smith, 1987; Finley, Stewart, & Yarroch, 1982).

There have been many studies that identified students' difficulties and misconceptions in electrochemistry from students' responses to conceptual multiple-choice questions or interviews. Allsop and George (1982) found that students had difficulty in producing scientifically accepted electrochemical cell diagrams and predicting the cell reactions. Ogude and Bradley (1994) reported pre-college and college students' misconceptions about the conduction in the electrolyte and electrical neutrality. Students participated in this study believed that electrons can flow through the salt bridge and in the electrolyte solutions and they showed wrong direction of the movement of either electrons or ions. In another article, Ogude and Bradley (1996) identified students' difficulties in relation to the aspects of cell components, cell emf and current electrode processes and terminology. The results of this study suggested that many students believed in the notion that electrodes are charged.

Garnett and Treagust (1992) conducted semi-structured interviews with 32 high school students in Australia to investigate students' misconceptions about galvanic and electrolytic cells. Students' responses revealed six areas of conceptual difficulties that are identifying anode and cathode in galvanic cell, the need for a standard half-cell, current in a galvanic cell, the charge on the anode and cathode in galvanic cells, identifying the anode and cathode in electrolytic cells, predicting the products of electrolysis and the magnitude of the applied emf.

Sanger and Greenbowe (1997) replicated Garnett and Treagust's interviews (1992) on galvanic and electrolytic cells and extended them on concentration cells. Students' misconceptions most commonly encountered involved the notions that electrons flow through salt bridge and the electrolyte solutions to complete the circuit.

plus and minus signs assigned to the electrodes represent net electronic charges and water is unreactive in the electrolysis of aqueous solutions. In addition to these misconceptions, which are also reported in Garnett and Treagust's study (1992), new misconceptions including the beliefs that half-cell potentials are absolute and can be used to predict the spontaneity of individual half-cell reactions and electrochemical cell potentials are independent of ion concentrations were identified.

Because learning is the interaction of new knowledge with the existing concepts, misconceptions interfere with subsequent learning (Nakleh, 1992). Therefore, for a meaningful understanding of the science concepts misconceptions have to be remedied. However, students' misconceptions are so firmly rooted that it is difficult to change them through traditional instruction because simply presenting students with logical arguments of the subject may make little sense in the context of students' own beliefs (Herron, 1990). For learning new information that is different from their intuitive ideas students need to engage and restructure their ideas rather than assimilate new information into an existing framework of understanding (Hynd et al., 1994).

Meaningful learning in science involves realigning, reorganizing or replacing existing conceptions to accommodate new ideas (Smith, Blakeslee & Anderson, 1993). This process has been called conceptual change. Posner et al. (1982) proposed a conceptual change model of how students' conceptions change under the impact of new ideas and new evidence. Conceptual change model describes learning as an active process in which conceptions of new experiences are built as a result of interaction with previous experiences (Posner et al., 1982). Learning in conceptual change model has been explained by two processes. If learners know little about the learning task the new

information can be incorporated with the existing ideas. This process was referred as "assimilation" by Posner et al (1982) and "conceptual capture" by Hewson (1981). On the other hand, learners may have a well-developed conception about the learning task that may conflict with the new knowledge. In order to accept the new knowledge learners restructure their existing ideas. This process was called "accommodation" by Posner et al. (1982) and "conceptual exchange" by Hewson (1981). Posner et al. (1982) stated four conditions to be fulfilled for accommodation to occur: (a) there must be dissatisfaction with the existing conception, (b) the new conception must be intelligible, (c) the new conception must appear initially plausible, and (d) the new conception must be fruitful.

Effectiveness of conceptual change approach in science education has been demonstrated by numerous studies (Hewson & Hewson, 1983; Champagne, Gunstone & Klopfer, 1985; Roth & Rosaen, 1991; Nussbaum & Novick, 1982; Chambers & Andre, 1997; Hynd et al., 1994). However, conditions of conceptual change model are not elicited trough traditional instruction. One of the instructional strategies based on conceptual change approach is the use of conceptual change text that is designed to dispel students' misconceptions. Conceptual change text attempts to activate learners' preconceptions, warn learners about common misconceptions and contrast them with the scientifically accepted conceptions through the use of examples and explanations. In these texts learners are asked explicitly to make prediction about a given situation before presenting the misconceptions and explanations about the given situation (Chambers & Andre, 1997).

Many studies have shown that conceptual change text helps students change their misconceptions. Alverman and Hague (1989) demonstrated that activating prior

knowledge and refuting misconceptions by the use of texts enhanced achievement test performance. Guzzetti et al. (1993) meta-analyzed the literature on conceptual change text and found that conceptual change text facilitates learning of science concepts. Hynd et al. (1994) investigated the effect of demonstration, discussion and refutational text on changing students' misconceptions about Newton's law of motion. The results suggested that only reading refutational text was effective at changing students' misconceptions. Chambers and Andre (1997) used conceptual change text to investigate how learning from traditional and conceptual change text was related to individual's prior interest, experience, and gender. The findings of this study indicated that conceptual change text led to better understanding of electrical concepts than traditional text did. Alverman and Hynd (1989) showed that discussing the ideas in the text after reading it resulted in significant conceptual change of ninth grade science students.

Previous electrochemistry studies (Allsop & George, 1982; Garnett & Treagust, 1992; Ogude & Bradley, 1994; Sanger & Greenbowe, 1997) provide us with an extensive list of electrochemistry misconceptions. Sanger and Greenbowe (2000) investigated the effect of computer animations and conceptual change instruction based on chemical demonstrations on students' conceptions of current flow in electrolyte solutions. The results suggested that conceptual change instruction was effective at dispelling students' misconception that electrons flow in aqueous solutions of galvanic cells although computer animations did not have an effect on students' responses to visual and verbal questions. This study addressed only misconceptions regarding current flow in aqueous solutions. There is a need for instructional strategies based on conceptual change approach to dispel students' misconception in galvanic and electrolytic cells. The aim of

the present study is to compare the effectiveness of conceptual change texts oriented instruction over traditional instruction on students' understanding of galvanic and electrolytic cell concepts.

Methodology

Research Design

In this study, pre-test post-test experimental design was used. Students in experimental group were exposed to conceptual change text as a supplementary material while students in control group were instructed through traditional instruction.

Sample

The subjects of this study consisted of 64 eleventh grade students enrolled in a chemistry course at a high school in Turkey. Students were selected from the two intact classes whose teacher volunteered to participate in this study. Each teaching approach used in this study was randomly assigned to each class. The experimental group consisted of 31 students while the control group had 33 students.

Instruments and Materials

Electrochemical Cell Concepts Test (ECCT). In order to compare students' understanding of electrochemical cell concepts in experimental and control group, a concept test whose distracters contain common students' misconceptions was developed. Firstly, the instructional objectives for the galvanic and electrolytic cell concepts were stated. Then, the literature related to students' misconceptions concerning galvanic and

electrolytic cell concepts was carefully examined. The items of the test were constructed according to the instructional objectives and students' misconceptions that were reported in Garnett and Treagust's (1992) and Sanger and Greenbowe's (1997) studies because these studies included almost all of the probable students' misconceptions found by other researchers. The ECCT contained 23 multiple-choice questions, each having one correct answer and 3 distracters most of which contained students' misconceptions concerning galvanic and electrolytic cell concepts. The content and face validity of the test was verified by a professor of chemistry, an associative professor of chemistry education and two chemistry teachers. The reliability of the test (Cronbach Alpha) was found to be 0.80. ECCT was administered before and after the instruction.

Science Process Skill Test (SPST). In order to measure students' science process skills including identifying variables, identifying and stating hypotheses, operationally defining, designing investigations, graphing and interpreting data, Science Process Skill Test which was developed originally by Burns, Okey, and Wise (1985) was used in this study. The test was translated and adopted into Turkish by Geban, Askar, and Özkan (1992). It contains 36 four-alternative multiple-choice questions. The reliability of the test was found to be 0.85. SPST was administered before the instruction.

Conceptual Change Texts (CCTs). The main aim of designing conceptual change texts (CCTs) was to promote conceptual change in students' understanding of electrochemical cell concepts. Therefore, CCTs were developed incorporating the four conditions suggested by Posner et al (1982). In CCTs, firstly, students were asked

questions to make them aware of their preconceptions. After the questions, an empty space was provided for the answer of the students to the given question. Then, they were informed about probable misconceptions related to the phenomena asked in the question. After that, a scientific explanation of the concepts was given by stressing that the scientific concepts are more rational. In order to make the new concept intelligible for the learner, reasons, situations and examples were provided to why the misconception is wrong and the scientifically correct concept is rational. It was expected that students having misconception are dissatisfied when they realize that their conceptions are wrong or not adequate to explain the phenomenon. Moreover, the previously learned concepts were reminded to students for making the new knowledge plausible. Finally, students were suggested to replace or integrate the newly learned concepts with their existing conceptions. In order to make the new concept fruitful students were asked additional questions. An excerpt of CCTs used in this study is presented in figure 1.

Treatment

This study was conducted over a 4-week period. The course was scheduled as three class hours per week. One week before the treatment, the teacher was trained to implement the study in her classrooms. Firstly, students' common misconceptions about galvanic and electrolytic cell concepts were discussed. Then, the four conditions of conceptual change (Posner et al., 1982) were explained by the researcher to the teacher. Next, the researcher and the teacher read the CCTs together. Finally, the implementation of CCTs, discussion strategies and data-collection procedure were discussed by the researcher and the teacher.

CONCEPTUAL CHANGE TEXT I

GALVANIC CELLS

Identifying the Anode and Cathode of Galvanic Cells

In Figure A you see a galvanic cell constructed by copper and magnesium electrodes.

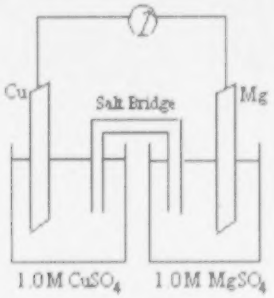

Figure A

$Cu^{2+}(aq) + 2e \rightarrow Cu(s)$, $E^o = +0.34V$

$Mg^{2+}(aq) + 2e \rightarrow Mg(s)$, $E^o = -2.36V$

Question 1. *In the above galvanic cell diagram drawn in Figure A, which electrode is the anode and which electrode is the cathode?*

Write your answer and your reason for your answer in the empty space provided below before you read the text If your answer is not correct you may have misconceptions. In that case read the text again.

Misconceptions about the Identification of the Anode and the Cathode of the Galvanic Cells

Misconception 1- *Some students think that the identity of the anode and cathode depends on the placement of the half-cells. Specifically, they believe that the anode is always the half-cell on the left-hand side of the cell and the cathode is the half-cell on the right-hand side of the cell.*

These students are wrong. This misconception may result from the students' observation that the textbooks and instructors mostly draw the anode on the left-hand side and the cathode on the right-hand side of the cells. The half-cell arrangement is arbitrary and shouldn't be considered as a method for identifying the anode and the cathode. What happens if you reverse the half-cells of the diagram in Figure A? Will the anode and cathode change? Of course not. The identity of the anode and cathode does not depend on the physical placement of the half-cells. It only depends on the reactions taking place in the half-cells.

Figure 1 *An Example of CCTs*

Before the treatment, ECCT and SPST were administered to the subjects in both groups as pre-test. Students were given one class hour to complete the tests. The directions were read to students and necessary explanations were made by the researcher.

One week after administration of the pre-tests, instruction related to electrochemical cell concepts started in both control and experimental groups. The students in control group were instructed by traditional method. Namely, the teacher provided instruction through lecture and discussion. Moreover, the teacher solved quantitative problems related to galvanic and electrolytic cell concepts. Meanwhile, students in the experimental group were first introduced to the topic to be learned. In this part of the instruction the teacher followed the same course outline and solved the same quantitative questions as in the control group. Then, the related CCTs were distributed to students at the end of the each topic and students were asked to study these texts before coming to class. Finally, the texts were discussed in the classroom at the end of the each topic by using the questions asked in CCTs. After the treatment ended, ECCT was administered as post-test to both control and experimental groups at the same time.

Data Analysis

The post-test scores were compared for the students who were exposed to conceptual change texts and students who received traditional instruction by performing analysis of covariance (ANCOVA). Previous studies showed that students' science process skills are significantly correlated with students' science achievement (Walkosz & Yeany, 1984; Pettus & Haley, 1980). Thus, in the present study two of the variables that may affect the post-test results were students' previous knowledge about galvanic and

galvanic and electrolytic cells and students' science process. In the ANCOVA model student' previous knowledge about skills were used as covariates in order to statistically equate groups in terms of these variables.

Results

The means and standard deviations for pre- and post-Electrochemical Cell Concepts Test scores across experimental and control groups are presented in Table 1.

As shown in Table 1, both experimental and control group showed an increase from the pre-ECCT to the post-ECCT. The increase in the mean score from the pre-test to the post-test of experimental group is greater than that of control group. Although the control group students had higher mean score from the pre-ECCT they had lower mean score from the post-ECCT as it is compared to the mean score of experimental group after the treatment.

Table 1 Means and Standard Deviations of ECCT Scores across Experimental and Control Group

		Pre-ECCT		Post-ECCT	
Group	n	Mean	SD	Mean	SD
Experimental	31	1.16	1.92	16.94	2.99
Control	33	4.06	3.93	11.39	4.29

SD: Standard deviation, N=64

In order to investigate the effectiveness of conceptual change text oriented instruction over traditional instruction on students' electrochemical cell concepts understanding (ECCU), ANCOVA was performed to analyze the data. Students' previous electrochemical cell concepts understanding (measured by pre-ECCT) and science process skills (measured by SPST) were predetermined as potential confounding variables to be statistically equalized among experimental and control groups. The results of ANCOVA are summarized in Table 2.

The results of ANCOVA demonstrate that group membership resulted in significant F at .01 level. This result indicates that there was a significant mean difference between the experimental and control groups on students' understanding of electrochemical cell concepts when the effects of students' prior electrochemical cell concepts understanding and science process skills were statistically controlled.

Table 2 Results of ANCOVA

Source	SS	df	MS	F
Covariate				
Pre-ECCU	40.44	1	40.44	3.05
ScienceProcess Skills	11.92	1	11.92	.90
Group Membership	453.72	1	453.72	34.22*
Error	795.53	60	13.26	
Total	1346.61	63		

*p< .01, Pre-ECCU: Pre-Electrochemical Cell Concepts Understanding

Examination of the adjusted means of post-FCCT scores showed that students exposed to CCTs had significantly better understanding of electrochemical cell concepts ($\overline{X}_{adj(exp)}$=17.64) than those exposed to traditional instruction ($\overline{X}_{adj(cont)}$=10.70).

Discussion and Implications

The purpose of this study was to compare the effectiveness of conceptual change text oriented instruction and traditional instruction on 11th grade students' understanding of galvanic and electrolytic cell concepts. The findings of the study showed that students who experienced conceptual change texts as a supplementary material had better understanding of galvanic and electrolytic concepts than the students who were taught through traditional instruction. This result implies that conceptual change texts were effective at preventing or dispelling students' misconceptions regarding galvanic and electrolytic cells because the distracters of the electrochemical cell concepts test included probable misconceptions. The success of the conceptual change texts was supported by the results of the previous studies. Hynd et al. (1994) concluded that CCTs were effective at promoting conceptual change in students' understanding of motion and objects. Maria and McGinitie (1987) showed positive effects of conceptual change texts on conceptual change. Chambers and Andre (1997) found that CCTs led to better understanding of electricity concepts than did the traditional texts. Guzzetti et al. (1993) meta-analyzed the literature on conceptual change text and conceptual change approaches and concluded that they facilitate learning of science concepts.

In this study the difference between experimental and control groups with respect to students; understanding of galvanic and electrolytic cell concepts can be attributed to the use of CCTs. The properties of CCTs promoted the acquisition of the new conceptions as a consequence of the exchange and differentiation of existing conceptions and the integration of the new concepts with the existing conceptual frameworks. CCTs made students aware of the inadequacy of their preexisting concepts. They pointed out that the scientific conception was more useful than the existing preconceptions by underlining the understandability and usefulness of the targeted scientific explanations because the explanations were supported by logic and examples. This characteristic of CCTs might lead the students to find the text more reliable. Also, CCTs helped students see the difference between misconception and scientific concepts. Moreover, by the use of the texts students had the opportunity to perceive the scientific explanations as a whole rather than as an isolated piece of information. Thus, students could relate ideas in the texts on to another. Therefore, concepts in the texts were learned in an integrated fashion rather than in isolation. During class discussion, the teacher helped students clarify their ideas and encouraged students to change their previous concepts. On the other hand, traditionally designed instruction did not deal with student' preconceptions or misconceptions. Therefore, the reason for the poor progress of the students exposed to traditional instruction might appear due to acquiring scientific conceptions with the continued presence of the alternative conception in their conceptual framework.

The results of this study suggest that CCTs were effective in addressing students' misconceptions and enabling them to develop a conceptual understanding that is more in line with the knowledge accepted by the scientific community. As misconceptions are so

resistant to change, it has been a challenge for the teachers to replace them with the scientific ones. It is hard for teachers to devote a large amount of time to develop and implement instructional activities to facilitate conceptual change. Especially in large classrooms where student-teacher interaction is minimized it is difficult to create effective learning environment. CCTs can be used effectively in both large and small classrooms to facilitate conceptual change. In addition, CCTs do not demand additional materials to be added into the instructional environment. Teachers and textbook writers can easily incorporate CCTs into the science texts or teachers can use them to supplement classroom instruction. Unlike to the other instructional strategies, CCTs can be reached by the students when needed.

In this study, CCTs were found to be effective at promoting students' understanding of galvanic and electrolytic cell concepts. Future research could focus on investigating the effectiveness of CCTs in other content areas and for different age groups. In this study it was not possible to identify which features of CCTs were responsible for positive effects. In the future studies, some of the features of the texts including questions, diagrams, and examples could be isolated and their influence on students' understanding could be examined. Finally, in this study it is not appropriate to say that the improvements in students' performance are permanent. There was a one-week delay between the administration of post-test and treatment. Further studies could be conducted to investigate the effect of CCTs for retention.

References

Allsop. R.T., & George N. H. (1982). Redox in Nuffield advanced chemistry. *Education in Chemistry, 10*, 57-59.

Alvermann, D. E., & Hague, S. A. (1989). Comprehension of counterintuitive science text: Effects of prior knowledge and text structure. *Journal of Educational Research, 82*, 197-202.

Alvermann, D. E., & Hynd, C. R. (1989). Effects of prior knowledge activation modes and text structure of nonscience majors' comprehension of physics. *Journal of Educational Research, 83*, 97-102.

Burns, J. C., Okey, J. R., & Wise, K. C. (1985). Development of an integrated science process skills test: TIPS II. *Journal of Research in Science Teaching, 22*, 169–177.

Butts, B., & Smith, R. (1987). What do students perceive as difficult in HSC chemistry? *Australian Science Teachers Journal, 32*, 45-51.

Chambers, K. S., & Andre, T. (1997). Gender, prior knowledge, interest, and experience in electricity and conceptual change text manipulations in learning about direct current. *Journal of Research in Science Teaching, 34*, 107-123.

Champagne, A., Gunstone, R., & Klopfer, L. (1985). Effecting changes in cognitive structures among physical students. In L. West and L. Pines (Eds.), *Cognitive structure and conceptual change*. London: Academic Press.

Cho, H., Kahle, J. B., & Nordland, F. H. (1985). An investigation of high school textbooks as source of misconceptions and difficulties in genetics and some suggestions for teaching genetics. *Science Education, 69*, 707-719.

Dole, J. A., & Niederhauser, D. S. (1990). Student's level of commitment to their naive conceptions and their conceptual change learning from texts. In J. Zutell and McCormick (Ed.). *Literacy theory and research: Analyses from multiple paradigms.* Chicago: National Reading Conference.

Driver, R., & Easly, J. (1978). Pupils and paradigm: A review of literature related to the concept development in adolescent science students. *Studies in Science Education, 5*, 61-84.

Driver, R. & Erickson, G. (1983). Theories in action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education, 10*, 37-60.

Finley, N.F., Stewart, J. and Yarroch, W.L. (1982) Teachers' perceptions of important and difficult science concepts. *Science Education, 66*, 531-538.

Garnett, P. J., & Treagust, D. F. (1992). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29*, 1079-1099.

Geban, O., Askar, P., & Ozkan, I. (1992). Effects of computer simulations and problem-solving approaches on high school students. *Journal of Educational Research, 86*(2), 5-10.

Gilbert, J. K., Osborne, P. J., & Fensham, P. J. (1982). Children's science and its consequences for teaching. *Science Education, 66*, 623-633.

Griffiths, A. K., & Grant, B. A. C. (1985). High school students' understanding of food webs: Identification of a learning hierarchy and related misconceptions. Journal of Research in Science Teaching, *22*, 421-436.

Guzzetti, B. J, Synder, T. E., Glass, G.V., & Gamas, W.S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly, 28, 116-159.*

Herron, J. D. (1990). Research in chemical education: Results and directions. In M. Gardner, J.G. Greeno, F. Reif, A. H. Schoenfeld, A. Disessa, & E. Stage (Eds). *Toward a scientific practice of science education* (pp.31-54). Hillsade, NJ: Erlbaum.

Hewson, P. W. (1981) A conceptual change approach to learning science. *European Journal of Science Education, 3*, 383-396.

Hewson, G. M., & Hewson, W. P. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching, 20*, 731-743.

Hewson, P. W., & Thorley, R. (1989). The conditions of conceptual change in classroom. *International Journal of Science Education, 11*, 541-553.

Hynd, C. R., & Alverman, D.E. (1986). The role of refutation text in overcoming difficulty with science concepts. *Journal of Reading, 29*, 440-446.

Hynd, C. R., McWhorter, Y. J., Phares, V. L., & Suttles, C. W. (1994). The role of instructional variables in conceptual change in high school physics topics. *Journal of Research in Science Teaching, 31*, 933-946.

Maria, K., & MacGinitie, W. (1987). Learning from texts that refute the reader's prior knowledge. *Reading Research and Instruction, 26*, 222-238.

Nakleh, M. B. (1992). Why some students don't learn chemistry? *Journal of Chemical Education, 69*, 191-196.

Nussbaum, J., & Novick, S. (1982). *A study of conceptual change in the classroom.* Paper presented in the National Association for Research in Science Teaching, Lake Geneva, Chicago.

Ogude, A.N., & Bradley, J.D. (1994) Ionic conduction and electrical neutrality in operating electrochemical cells. *Journal of Chemical Education, 71,* 29-31.

Ogude, A.N., & Bradley, J.D. (1996) Electrode processes and aspects relating to cell emf, current, and cell components in operating electrochemical cells: Pre-college and college student interpretation. *Journal of Chemical Education, 71,* 29-31.

Pettus, A. M., & Haley, D. (1980). Identifying factors related to science process skill performance levels. *School Science and Mathematics, 80,* 273-276.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66,* 211-227.

Roth, K. S., & Rosaen, C. L. (1991). *Investigating science concepts trough writing activities.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Fontana, WI.

Sanger, M. J., & Greenbowe, T. J. (1997) Common student misconceptions in electrochemistry: Galvanic, electrolytic, and concentration cells. *Journal of Research in Science Teaching, 34.* 377-98.

Sanger, M. J., & Greenbowe, T. J. (2000). Addressing student misconceptions concerning electron flow in aqueous solutions with instruction including computer animations and conceptual change strategies. *International Journal of Science Education, 22,* 521-537.

Smith, L. E., Blakeslee, D. T., & Anderson, W. C. (1993). Teaching strategies associated with conceptual change learning in science. *Journal of Research in Science Teaching, 30,* 111-126.

Walkosz M., & Yeany, R. (1980). *Effects of lab instruction emphasizing process skills on achievement of college students having different cognitive development levels.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (57th, New Orleans, LA, April, 1984

Zietsman, A. I., Hewson, P. W. (1986). Effect of instruction using microcomputer simulations and conceptual change strategies on science learning. *Journal of Research in Science Teaching, 23,* 27-39.